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COMMENT

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This article is a comment on *Crago et al.* [2016], doi:10.1002/2016WR019753.

Key Points:

- Evaluation of a revised complementary relationship model in estimating land surface evapotranspiration
- The x_{min} proposed by C16 may lose its physical meaning under the conditions of strong available energy but weak winds
- The Penman-based method is more appropriate than mass-transfer-based method in deriving the E_{pads} to rescale the CR with x_{min}

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Comment on “Rescaling the complementary relationship for land surface evaporation” by R. Crago et al.

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Abstract The generalized complementary relationship (GCR) model of *Brutsaert* (2015) has been widely applied to estimate land surface evapotranspiration (E) over Chinese eastern monsoon region, Loess Plateau and Australia. However, *Crago et al.* (2016, hereinafter C16) recently noted a deficiency in one of his boundary conditions and proposed a novel approach to improve it. The key of this approach is to determine the ratio (x_{min}) of the potential evapotranspiration (E_{po}) to the apparent potential evapotranspiration for an entirely dry surface (E_{pads}) at which E tends to be vanishing. As seen, the physically reasonable range of x_{min} should be between 0 and 1. The present comment reports that the x_{min} in C16 may become invalid under conditions of relatively strong available energy but weak winds if E_{pads} is calculated by the mass-transfer-based method, thereby causing unrealistic estimation of E. A more preferable way to determine E_{pads} is still based on the traditional Penman-based equation with consideration of the characteristics of dry air in which E_{pads} occurs.

1. Introduction

Recently, *Crago et al*. [2016, hereinafter C16] drew attention to one of the boundary conditions of *Brutsaert*'s [2015] generalized complementary relationship (GCR) model, which may be problematic because of an ill-defined physical constraint. That is, the absence of actual evapotranspiration (E) does not suggest that the ratio of the potential evapotranspiration (E_{po}) to the apparent potential evapotranspiration (E_{pa}) approaches zero. The latter is due to, as supposed by *Brutsaert* [2015], either a diminishing E_{po} or an infinite E_{pa}. Owing to solar and wind's natural properties, we agree with C16 that the “$ET_p \rightarrow 0$” may be questionable since the available energy and the vapor transfer in the atmospheric boundary layer are not infinite. In this way, C16 proposed a maximum value as the upper limit of E_{pa} (i.e., E_{pads})—”*the value E_{pa} would have if the regional surface was devoid of all moisture*””—to normalize E_{po} as x_{min}, thereby replacing the low boundary of $x=0$ in *Brutsaert* [2015]; specifically,

$$x_{min}=\frac{E_{po}}{E_{pads}} \tag{1}$$

$$E_{po}=\alpha\frac{\Delta(T_{ws})}{\Delta(T_{ws})+\gamma}Q_n \tag{2}$$

$$E_{pads}=\frac{Le[q^*(T_{ws})-0]\rho k^2 U_1}{\ln\left(\frac{z-d_o}{z_{ov}}\right)\ln\left(\frac{z_1-d_o}{z_{om}}\right)} \tag{3}$$

where Q_n is the available energy that is equal to the net radiation less the ground heat flux. All other variables in equations (1)–(3) have been carefully defined in C16 (notice that all of them are based on a daily scale). In particular, the dimensionless *Priestley and Taylor* [1972] coefficient α in equation (2), which typically ranges from 1.1 to 1.32 [*Szilagyi et al.*, 2017], must be calibrated using the measured E and a given complementary relationship (CR) model, as illustrated in C16 or *Brutsaert* [2015]. C16 also noted that the height of z should be low without consideration of atmospheric stability on a daily scale (i.e., neutral conditions). This is valid since equation (3) is derived from the logarithmic profile of wind and humidity within the dynamic sublayer (i.e., entirely turbulent), which normally spans an order of 10^0–10^1 m [*Brutsaert*, 1982, p.54].

2. Issue With the Rescaling Using x_{min}

By virtue of the invariability of T_{ws} [*Szilagyi and Schepers*, 2014], E_{pads} is the maximum evapotranspiration that would occur from a small wet patch surrounded by a nonpotential environment. Except for the state of exhausted air humidity (i.e., 0) in the present equation, which reflects "*no source of moisture*", equation (3) is almost identical to the EP5 of *Granger* [1989] and the equation (8) (with e^*_1 taken as e_s^*) of *Crago and Crowley* [2005]. Although *Granger* [1989] stated theoretically that EP5 > EP2, he did not provide any observational evidence to support it. Further, although C16 noted that "*E_{po} is primarily a function of available energy and E_{pads} is largely a function of the efficiency of mass transfer*", this does not necessarily mean that $E_{pads} > E_{po}$ indefinitely, due to their different governing factors. Indeed, as shown below, x_{min} may be ≥ 1 under conditions of weak winds but strong available energy if E_{pads} is calculated by mass-transfer-based equation (3), which then loses its original physical meaning introduced by C16.

To illustrate, imagine a common homogeneous terrain with a mean plant height of 10 cm, air pressure of 101.3 kPa, and T_{ws} of 10°C. With the settings above, one can derive E_{po} and E_{pads} using given Q_n and U_1 (for convenience the wind speed at 2 m high is used here) values from either ground measurements or reanalysis data sets. Although it is not easy to determine the upper limit of air flow velocity without any

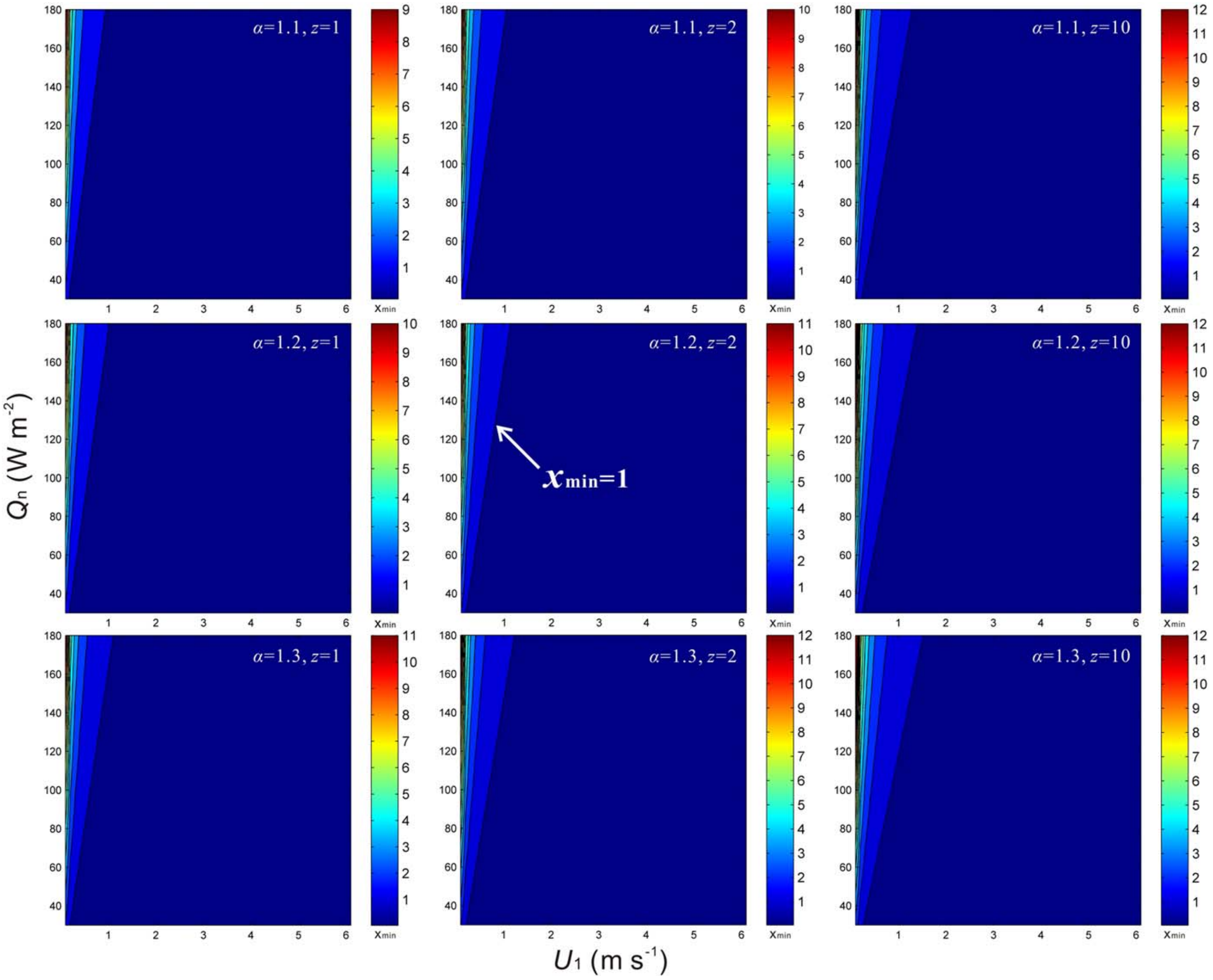

Figure 1. x_{min} values (equation (1)) under different conditions of available energy (Q_n) and 2 m high wind speed (U_1), where $\alpha = 1.1$, 1.2 and 1.3 in equation (2), respectively; and $z = 1$, 2 and 10 m in equation (3), respectively. The rightmost isoline in every panel (as exemplified in the center panel) indicates $x_{min} = 1$, with the values to the left of this line representing $x_{min} > 1$.

information on weather and topography, common sense suggests that $U_1 \geq 0$. Besides, a value of 180 W m^{-2} for the maximum daily Q_n over most mid- and low-latitudes is undoubtedly realistic, as evidenced by a variety of in-situ observations [e.g., *Baldocchi et al.*, 2004; *Giambelluca et al.*, 2016; *Scott et al.*, 2004; *Timm et al.*, 2014; *You et al.*, 2017]. Therefore, we uniformly sampled Q_n in the range of 30–180 W m^{-1} (intervals of 2.5 W m $^{-1}$) and U_1 in the range of 0.1–6.1 m s^{-1} (intervals of 0.1 m s^{-1}) to calculate all possible x_{min} values under different Q_n and U_1 scenarios. (It is worthwhile to emphasize that we are not intended to show how x_{min} would vary with changes of Q_n and U_1 since C16 has already assumed that "*holding available energy, wind speed, and T_{ws} constant*" in defining E_{pads}; rather, our aim is to quantify x_{min} values for any Q_n and U_1 combination.)

Considering the possible ranges of α (equation (2)) and z (equation (3)) mentioned previously, we directly tested α values of 1.1, 1.2, and 1.3. In addition to a height of 2 m used by C16, other heights were also examined (i.e., $z = 1$ and 10 m) because of possible changes of the dynamic sublayer. Figure 1 shows x_{min} values under different Q_n and U_1 conditions. The results in Figure 1 suggest that x_{min} adopts values > 1 during relatively low U_1 and high Q_n conditions. Taking $z = 2$ m and $\alpha = 1.3$ as an example, a $U_1 \leq 1$ m s^{-1} would result in a failure of equations (1–3) to represent the minimum realistic value of x of *Brutsaert* [2015] as long as $Q_n > 145$ W m^{-2}. For a given U_1, the threshold of Q_n, which yields an $x_{min} > 1$, decreases as α and z increase. This ultimately causes the calculated E to become unrealistically negative according to the equation (14) of C16.

3. Summary

In short, the present comment is to caution the possible deficiency of using the C16 approach to estimate E. This is particularly important during summer when the solar radiation usually appears to be intense, while the wind speed does not necessarily behave similarly at the same time. Moreover, given that terrestrial wind stilling is globally widespread [*McVicar et al.,* 2012], one would need to pay more attention on future model application. To clarify, we think it may be safe to implement the new boundary with x_{min} (equation (1)) in the CR model of C16 for relatively higher wind velocities or much rougher surfaces, which dramatically increase the bulk transfer efficiency.

The primary idea of normalizing E_{po} for a physically reasonable x_{min} at which E approaches zero is to determine the theoretical maximum E_{pa}. In this context, a more appropriate manner is still applying the Penman-based equation [*Penman*, 1948] and considering the properties of completely dry air above the evaporating surface, as was done by *Szilagyi et al*. [2017].

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